Demystifying HVAC

What is a Heat Pump?

By Ron Prager

Roof mounted heat pumps, water-source heat pumps, split system heat pumps; you know they are used to air condition and heat your stores, but how do they work, and in what way are they different from normal air conditioning units?

What they are and how they work:
Technically, almost any air conditioning system can be considered a heat pump. Air conditioners are used to transfer heat from air at one set of conditions to air or water at a different set of conditions. The rooftop air conditioner that cools one of your stores is actually removing heat from the air within the store and transferring it to the air outdoors. This air enters the unit at 80°F and 50% relative humidity and after passing through the indoor coil, it leaves the unit at a temperature of 55°F and a relative humidity of 100%. The heat that has been transferred from this air is carried by a refrigerant (Freon 22) to the outdoor, or condenser coil.

Obviously, outdoor ambient temperatures can be quite high during the periods when a store requires air conditioning. The refrigerant must transfer the heat it removed from the air in the store to the outdoor air, but the outdoor air can be at a temperature of 95º F or more. Because we need to transfer this heat to air that is 95°F, the temperature of the refrigerant we are removing the heat from, must be substantially higher than the outdoor ambient temperature. The system is designed to blow outdoor air over tubes containing refrigerant at a temperature that is approximately 25°F warmer than the ambient air, so that the heat within the refrigerant can be transferred to the outdoor air.

The air conditioner is removing heat from area of low temperature (your store), and transferring it, or "Pumping it," to an area of higher temperature (the air outside). Remembering high school physics, if the outdoor temperature were substantially colder than the temperature in your store, the heat would flow naturally from the area of high temperature to the area of low temperature. Hence, there would be no need to add the mechanical energy required to pump the heat from a lower temperature area to a higher temperature area. The energy or "Pumping," is required because we are forcing heat to be transferred in a direction that is opposite to the way heat will flow naturally.

While any air conditioner can be considered a heat pump as described above, the HVAC industry considers "Heat Pumps," to be air conditioners that have the ability to operate with a reverse cycle. All of us have walked by a window air conditioner or a residential condensing unit on a summer day and felt the hot air being discharged by these machines. As described above, the temperature of the air leaving these units has increased because the refrigerant in the system picked up heat from the air inside the house, and that heat is being transferred to the air passing over the outdoor coil, thereby raising the temperature of the air.

Now think about what would happen if we took that window air conditioner out of the window, turned it 180°, put it back into the window, and allowed the unit to operate. Instead of transferring heat from inside the room to the outdoors, the air conditioner would be transferring heat from the outdoor air to the air within the room. On a 95°F day this would be objectionable because we would end up with 125° temperatures inside the conditioned room and a machine that was attempting to cool the great outdoors.

However, think about this process on a 45°F day. Our air conditioning unit, installed backwards, would be removing heat from the outdoor air at 45°F and transferring it to the air within a room at 70°F. This heating process is called "Reverse cycle air conditioning," and this is what a heat pump is designed to do. It is designed to cool a space when operating as an air conditioner and it is designed to heat a space when the cycle is reversed. The actual reversal of the cycle is accomplished by reversing the flow of refrigerant and causing the indoor coil and the outdoor coils to switch roles.

Normally, the indoor coil operates as the evaporator coil where heat is absorbed by vaporizing or evaporating the refrigerant, and the outdoor coil operates as the condenser coil, where heat is removed from the hot gaseous refrigerant, and the refrigerant condenses into a liquid. Through the use of an electrically operated valve and some check valves, it is possible to switch the refrigerant flow, so that the indoor coil becomes the condenser and the outdoor coil becomes the evaporator coil. Our air conditioning unit is now capable of delivering heat to our store.

The good and the bad:
This sounds like a wonderful invention. We start with an air conditioner, and with the addition of a little hardware we now have the capability of heating our store. No gas piping is required, and there is no danger associated with combustion. Unfortunately, like most things in life, there is no free ride. The good news is that heat pumps can deliver heat to a space with an efficiency that is 3 times as efficient as electric resistance heat. Yes, this means that if it cost $30 per week to heat a space with electric resistance heat, it would cost $10 per week to heat the space with a heat pump. This measure of efficiency compared to electric resistance heat is defined as the "Coefficient of performance" aka (COP). Unfortunately, this coefficient of performance varies with the outdoor temperature. This makes sense when you think about it, because it is going to be a lot easier to remove heat from 50ºF outdoor air than it is to remove heat from 10ºF outdoor air. As a matter of fact, that COP we were speaking of earlier may drop from 3 at an outdoor temperature of 60ºF to 1.1 at an outdoor temperature of 10ºF.

We also need to look at the heating capacity required by our store, and the heating capacity provided by a heat pump. Normally, a heat pump is capable of delivering a maximum of 1.25 times its cooling capacity as heating capacity. If it provides 100,000 BTUH of cooling it will provide 125,000 BTUH of heating at maximum capacity. However, maximum heating capacity occurs at 70ºF outdoor temperatures, when we need it least. We stated above that operating efficiency drops off as outdoor temperature drop. It is also true that heating capacity drops as outdoor temperatures drop. If the heating requirement of a space is lower than the capacity of the heat pump, auxiliary electric heat must be installed within the unit to make up the shortfall in heating capacity as outdoor temperatures fall.

The lowest outdoor temperature at which a heat pump can satisfy the heating requirements of a space without the use of auxiliary electric heat is defined as the "Balance point." This balance point is determined by the heating requirement of the space at different outdoor temperatures, the heating capacity of the heat pump, and the lowest outdoor ambient design temperature. A graph is constructed using this information to determine at what outdoor temperature the heat pump can no longer meet the heating requirement of the space.

One advantage of heat pumps, when compared with gas fired heat, is the cost savings due to elimination of a natural gas service and gas distribution piping. Once again however, we must look at the local climate to determine if auxiliary electric heat is required. The electric service and feeder sizing might have to be increased to accommodate auxiliary heat and this might cancel out the gas service savings.

We can see that climate, required capacity, and cost of different types of energy will all be determining factors when considering the application of a heat pump system. If fossil fuels are not available, heat pumps are probably the way to go because they will always cost less to operate than electric resistance heat, and resistance heat is the only available alternative. Where low cost electric power is available (Usually where power is generated by hydroelectric plants,) heat pumps should be considered, because it may cost less to operate heat pumps than it will to operate gas fired equipment. Where climates are relatively mild year round, heat pumps may also be applied well. Think of the heating requirements in cities like Orlando, San Francisco, and Houston. Very rarely do temperatures drop below 50ºF, so capacity and efficiency of heat pump systems remain high. In addition, the number of hours of annual heating operation is very low. This means that even if the operating cost of gas fired equipment is lower than the operating cost for heat pumps, the payback period might be so long that heat pumps become the better choice.

Service considerations:
There are a few things that must be considered when dealing with heat pumps from a maintenance and service standpoint. The first item to consider is the fact that the compressor in a heat pump system may see considerably more hours of use than the compressor in a unit with gas heat, for the same time period. This makes perfect sense since we are using the compressor in both heating and cooling modes. Compressors in heat pumps are also forced to operate over a much greater variety of conditions. This requires the installation of several additional components and acts to shorten compressor life.

During heating operation, at low outdoor temperatures, frost forms on the outdoor coils. If the frost were allowed to build up to the point where the coil was completely blocked, the unit's capacity would be severely diminished and the compressor could be damaged due to liquid slugging. Therefore, heat pumps have to be equipped with controls that monitor and detect when the outdoor coil becomes iced over and put the unit into a defrost cycle. These controls then have to determine when the coil has been defrosted and terminate the defrost cycle.

Heat pumps also use a device called a suction accumulator that is not normally found in other air conditioning units. The accumulator is actually a tank that is installed just before the compressor, in the suction line. The purpose of this device is to allow any liquid that finds its way to the compressor to flash off into vapor prior to entering the compressor. The accumulator also provides a way for oil that is mixed with the liquid refrigerant to be returned to the compressor.

Heat pumps use an electrically operated valve to switch refrigerant flow. As stated earlier, they may also be equipped with auxiliary electric heaters. The thermostats or EMS (energy management systems) that control heat pumps may need to meet special requirements to control these items properly. There are currently three different variations of control wiring for heat pumps. These are based upon how the reversing valve is to be controlled. Some manufacturers set up a unit so that it is in the heating mode when the valve is energized. Some manufacturers energize the valve when the unit is in cooling mode. Some manufacturers have the thermostat control the valve operation through the use of an additional control wire and other manufacturers set up their control wiring the same as the standard wiring for a non-heat pump unit. In addition, there are several different control requirements that are dependent on the way electric heaters are to be controlled. As equipment becomes more complex it becomes more expensive to service. This is due to the fact that there are more components to fail and fewer technicians who are capable of diagnosing and making repairs easily.

The nature of heat pumps dictates that some of the refrigerant piping serves a dual purpose. The refrigerant flow in the liquid line of a heat pump actually changes direction. Most air conditioning systems have a liquid line drier mounted in this piping. Heat pumps also have a drier mounted in the liquid line, but it must be of a bi-flow type so that it filters refrigerant flowing in both directions. When the refrigerant piping is fabricated and installed on a split system air conditioner, there are certain procedures that are followed to ensure good oil return to the compressor. These include installation of oil traps and correct pitching of piping as well as the installation of double risers. The fact that heat pumps use the refrigerant piping for different purposes during heating and cooling operations prevents the installer from following these procedures. For this reason, split system heat pumps must be applied and piped strictly according to the equipment manufacturer’s recommendations. I personally, avoid the use of split system heat pumps if another option is available as my experience has been that they are more prone to failure than other types of systems.

Water Source Heat Pumps:
Up until this point, we have been discussing heat pumps that transfer heat between outdoor air and indoor air. What if we replaced the outdoor air with a never ending flow of water at a temperature between 75ºF and 80ºF? In cooling mode, our heat pump could remove heat from the air in our store and transfer it to the water. Due to the fact that the

water is maintained at a maximum temperature of 80ºF, versus an outdoor air temperature of 95ºF, it takes less work to transfer the heat to the water than it does to the air. Therefore, the water cooled air conditioning cycle is more efficient than the air cooled cycle. In heating mode, our heat pump is removing heat from 80ºF water and transferring it to the air in our store. Because the water temperature is so high, compared to winter outdoor air temperatures, our heat pump heating capacity remains high and constant. These units may be able to deliver heat at a COP of 3.5 or better.

When looked at individually, water source heat pumps are extremely efficient, but remember what I said earlier about no free ride. We were assuming an unlimited source of 75ºF to 80ºF water. When we look at relative efficiencies we need to look at the energy and cost associated with providing that water source. Typically, the water is circulated throughout a closed loop in the building. Heat is typically removed from the water by a cooing tower and heat is added to the loop by a boiler. The cost of tower, boiler and circulating pumps must be added to the cost of heat pump operation when looking at comparative system operating costs and efficiencies. While on the subject of circulating pumps, the pumps used to circulate hot water in a hydronic (hot water) heating system are sometimes called "Heating pumps." These centrifugal water pumps have nothing to do with and should not be confused with the heat pumps discussed herein.

The water source heat pumps described above really excel in terms of efficiency and operational cost in two applications. The first application (typically residential) is the use of water source heat pumps with geothermal loops. In this application, the water is pumped through long lengths of piping buried in the ground. This type of system is advantageous because the ground temperature below the frost line remains both stable and warmer in winter than the outdoor air temperature. This ground temperature is almost constant and is far cooler than the outdoor air in summer. In addition, the transfer of heat from and to the piping is passive in that no external energy is required to heat and cool the loop water. These geothermal systems are relatively new and are still being improved. They do require a significant amount of land to be available for installation of the piping system.

The second application where water source heat pumps have an extreme advantage over other systems is, in buildings where building operation requires that a large portion of the space requires cooling year round, while other areas require seasonal heating. Perimeter space in a large office building or in a mall may require seasonal heating and cooling. Interior or core space may require cooling on a year round basis. Outdoor air for the building requires heating in winter and cooling during the summer. While a cooling tower is required to remove heat from the loop water during summer operation, no boiler or heating input is required in winter because the units that are operating in heating mode are removing heat from the water and the units that are operating in cooling mode are adding heat to the water. This is an engineer's dream in terms of efficiency.

Heat pump systems have their place in the retail store arena. Like most systems, they must be applied carefully according to good design practice. The operating costs and relative efficiencies of heat pump systems must be considered when comparing types of systems and applications. Most important, from the facilitator's point of view, the cost, and ease of servicing these systems must be examined and it is imperative that they be installed and applied according to the manufacturer's instructions and recommendations.